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Measuring Farmstead Odors

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The nose and the brain work together to create what we perceive as odor. Our sense of smell is activated when the nose captures odor-causing chemicals, called odorants, from the air. Nerves located in the nose pass a message on to the brain when they detect an odorant. The brain then analyzes the message about the odorant.

Scientists have identified hundreds of odorants forming the collection of smells known as farmstead odors. Table 1 is a partial list of the groups of odorants released by animals and by breakdown of manure. Under each group is a list of individual chemical compounds that are commonly found in manure odors.

Odor Perception: Detection, Recognition, and Notes

The brain makes decisions about the odorant at certain concentrations. In Table 1, two numbers are listed next to the odorants; these are the detection and recognition levels for the odorants. The first number, the detection level, is the concentration in parts per billion (ppb) at which the average, healthy person first notices an odor. People cannot recognize the odor at the **detection level,** but they know they smell "something." For example, the brain notices an odor when there are 17 parts of ammonia in one billion parts of air. The second number is the **recognition** level. At this concentration, the brain begins to recognize the odorant as a distinct scent. The average human recognizes the scent of ammonia cleanser when the concentration of ammonia gas reaches 37,000 parts per billion.

Values for detection and recognition levels can be slightly difficult to comprehend. Let's look at a few examples. A person is standing on the floor of the Louisiana Superdome. The Superdome, a very large building, contains 125 million cubic feet of air space. In metric units, this equals 3.5 billion liters. Now, let's release hydrogen sulfide into the Superdome. The detection level of hydrogen sulfide given in Table 1 is 0.5 ppb. Although hydrogen sulfide is a gas, it has a weight based on the size of its molecule. A person would smell "something" if one tenth of an ounce of hydrogen sulfide were mixed in with clean air in the Superdome. The recognition level for hydrogen sulfide is 4.7 ppb. The brain would begin to recognize a faint rotten egg smell if one ounce of hydrogen sulfide was released. Skatole is a large nitrogen-containing compound largely responsible for making manure smell like manure. Skatole's detection level is 1.2 ppb, or less than one ounce of skatole in the Superdome. The recognition level of skatole is

470 ppb; therefore, the brain would not recognize a manure-like smell until about 20 pounds of skatole were released into the building.

From the previous two examples, you can see that detection and recognition levels are not always directly related. Humans can detect and recognize hydrogen sulfide at very low levels. Skatole, on the other hand, is easily detected, but only becomes recognizable at larger doses. Ammonia is an extreme example. The average human would notice "something" in the Superdome if two ounces of ammonia gas were released. They would not recognize it as ammonia until nearly 220 pounds were added!

Farm odors are never pure samples of one odorant, but rather a mixture of many different odorants. Recently, a sample of air was taken from a hog building in Germany. When chemists analyzed the sample, they measured at least 11 different organic acids, but none of the individual acids were present at detectable levels. Because the individual odorants were below the detection level does not mean they could not be smelled. The brain lumps similar odorants together as a group. You would smell something in the barn, because your sense of smell lumps all 11 organic acids together into a composite, "sour meat" smell.

Perfumers and people who blend odors call a group of odorants making a distinct scent an odor note. Let's go back to the Superdome to illustrate odor notes. If you are standing in the middle of the football field, you may not hear one person way up in the stands blowing softly into a plastic trumpet. If a hundred people blow into plastic, brass, and tin trumpets all at the same time, you will definitely hear a "note."

Odor Concentration

Farmstead odors always occur as mixtures of odorants. It is difficult and expensive to measure the concentration of each odorant in a sample. Instead, odor scientists measure the concentration of odors as a whole by grabbing a sample and presenting it to a panel of trained sniffers. The sample is diluted with odorless gas until half of the panel can no longer smell anything. When 50 percent of the sniffers can no longer detect an odor, we say the sample has been diluted to the **detection threshold**. Detection threshold is similar to detection level discussed in the previous sections. Detection threshold is the detection level of a mixture of odorants at the conditions given in the experiment.

The ratio of odorless gas to sample is called the dilution factor. **Dilution factor** is a good measure of odor concentration. The odor threshold standard used by the European Union gives odor concentration at the detection threshold the arbitrary value of one odor unit per cubic meter (OU/m^3). For example, an air sample taken from inside a dairy barn is diluted 100 times until half of the people on a panel could no longer detect an odor. The air inside the dairy barn has an odor concentration of 100 OU/m^3. Other odor threshold standards do not state odor concentration in odor units per volume. Since the dilution factor is a ratio, it has no units; therefore, the inverse of dilution factor is simply given the units OU. No matter what standard you use, the concept is the same: dilute the sample to the detection threshold, then use the inverse of dilutions as odor concentration.

Table 1. Components of Manure Odors.

Groups and Individual Odorants	Detection Level (ppb)	Recognition Level (ppb)	Odor Description
Organic Acids			

Acetic Acid	10.2	1,000	Vinegar
Propionic Acid	3.6	300	
Butyric Acid	1.1	1	Sour Meat
Iso-Valeric Acid	1.2	-	
Valeric Acid	-	20	
Alcohols, Aldehydes, Ketones			
Methanol	-	100,000	Sweet
Formaldehyde	-	1,000	Straw, pungent
Acetylaldehyde	-	210	Fruity, pungent
Acetone	4.0	100,000	Sweet, pungent
Methyl Ethyl Ketone	-	10,000	Sweet
Phenolic Compounds			
Phenol	5.7	1,000	Medicinal
p-Cresol	8.0	-	
Nitrogen Compounds			
Ammonia	17	37,000	Sharp, pungent
Methylamine	-	2.1	Fishy, pungent
Dimethlyamine	37	37	Fishy, pungent
Diethylamine	-	500	Fishy, pungent
Indole	1.0	-	Fecal
Skatole	1.2	470	Fecal, pungent
Sulfur Compounds			
Hydrogen Sulfide	0.5	4.7	Rotten Egg
Methyl Mercaptan	0.5	2.1	Rotten Cabbage
Dimethyl Sulfide	1.1	1.1	Rotten Vegetable
Diethyl Sulfide	6.0	6.0	Rotten Vegetable

Odor Character

We use the term character to describe what an odor smells like. Odor character does not change with concentration. Ammonia at 10 OU/m^3 smells the same as ammonia at 100 OU/m^3. The fourth column of Table 1 lists identifying terms used to describe the character of selected odorants. Some of the descriptive words listed in Table 1 conjure up pleasant responses. Many alcohols and ketones have "sweet" and "fruity" descriptors. Farmstead odors are mixtures of many odorants. What is pleasant by itself may be unpleasant when mixed with other compounds. In addition, unpleasant odors often add a tinge or edge to a pleasant smelling mixture. Surprisingly, indole, a nitrogen-containing compound described in Table 1 as having a "fecal" odor, is a major component in jasmine-scented perfumes.

Odor character is subjective or qualitative. In other words, it is difficult to assign a number to character. Two methods to quantify or assign a numerical value to odor character are by offensiveness and by hedonic tone.

Offensiveness

It is difficult to say exactly what farmstead odors smell like, and in the final analysis, the exact description of the smell may not matter. People know if they like the smell or not. Offensiveness is an attempt to add degrees of good and bad to "yes, it smells good - no, it smells bad" phenomena. The procedure involves three steps: an odor panel measures offensiveness; a series of samples is diluted to equal odor strength or intensity; and panelists are asked to rank the offensiveness of each sample on a scale of 0 to 5 (0 = inoffensive, 5 = strongly offensive).

Hedonic Tone

Hedonics is the science of comparisons. Odor panelists compare an unknown sample to a set of known odorants. The panel decides which of the known odorants best describe the odor. The odor is assigned a rating, called the hedonic tone, based on the comparisons. Hedonic tone provides a sense of the relative pleasantness of a sample. Pleasant odors have positive hedonic tones, and negative hedonic tones indicate unpleasant odors. Table 2 lists hedonic tones for common agricultural odors as well as some of the odorants listed in Table 1. If dead animal scent has a hedonic tone of -3.75, and rotten fruit -2.76, we can assume most people find rotting animal flesh more offensive than rotting fruit.

Table 2. Hedonic Tone of Common Agricultural Odors.

Odor	Hedonic Tone
Strawberry	2.93
Apple	2.61
Hay	1.30
Grain	0.63
Mushroom	0.52
Isovaleric Acid	-1.57
Butanoic Acid	-1.77
Mercaptans	-2.30
Ammonia	-2.47
Rotten Fruit	-2.76
Urine	-3.34
Manure	-3.36
Dead Animal	-3.75

Odor Intensity

Offensiveness tells us how bad an odor smells, and concentration gives us an idea how many molecules of odorants are floating in the air, but neither measure tells how strong an odor smells. For that, we need a third measure - odor intensity. Odor intensity is the direct measurement of a person's reaction to an odor. To measure odor intensity, scientists ask a panel to describe the strength of an unknown odor without knowing the odor concentration or dilution factor. A commonly used scale ranks intensity between 0 and 6 (0 = no odor, 6 = extremely strong odor).

Intensity experiments usually attempt to determine the relationship between concentration and intensity. An original sample of odorous gasses is mixed with clean

air in a series of dilutions and presented to a panel. Figure 1 shows the results of a series of dilutions performed on two common sources of farmstead odors - chicken house exhaust and liquid hog manure. These results demonstrate three concepts needed to understand intensity.

First, every mixture of odorants has its own relationship between concentration and intensity. Similar mixtures of odorants, such as five different samples of chicken house exhaust, have similar concentration-intensity relationships. Second, intensity and concentration are not a one-to-one relationship. If you dilute an odor sample in half, the odor intensity is not diminished by one half. In order to diminish a strong chicken house odor (I = 4) to a faint odor (I = 2), we would have to dilute a 40 OU/m^3 sample down to 5 OU/m^3. This is an 8-fold dilution.

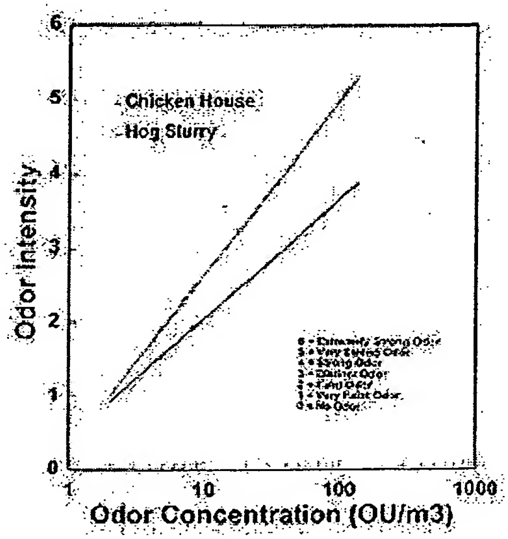

Figure 1. Relationship of Odor Intensity and Odor Concentration.

Third, intensity and character are not related. According to the results shown in Figure 1, if odor concentrations are held equal, the panel would say chicken house odor is more intense than hog slurry odor. This does not mean the chicken house smells worse than the hog slurry; it only means the chicken house smells stronger than the hog slurry. Complete description of an odor involves measuring both intensity and character. Perfumes give off high-intensity odors, but these odors are not offensive. An apple pie baking in the oven smells both strong and pleasant. Skunks release strong and offensive odors. A glass of water smells neither strong nor offensive because it has no smell at all.

Odor Persistence

Perfumers are masters in the art of blending many odors to form complex mixtures known as perfume. If one distinct odor is a note, then a mixture of many odors is a chord. Perfumers also recognize that a chord of odors can change with time. Perfumers group notes according to their relative volatility or persistence. The most persistent odors are base notes. The least persistent odors are top notes. Odorants with medium volatility are called middle notes or modifiers. When perfume is placed on the skin, the first scent smelled is the top note. Since top notes are made of volatile (or short-lived) odorants, they fade with time. Base notes remain long after the top notes have faded. Middle notes give the perfume "lift" or "body" throughout the life of the scent.

Table 3. Likely Grouping of Manure Odor Notes

Based on Relative Volatility of Odorants.

Top Notes	Middle Notes	Base Notes
Hydrogen sulfide Ammonia	Aldehydes Alcohols Ketones Amines Mercaptans Organic Sulfides (2 to 4 carbons)	Organic Acids Phenolic Compounds Indole and Skatole Organic Sulfides (more than 5 carbons) Dust borne odorants

Farmstead odors are also chords of many notes. Odorants in the manure chord can be grouped in notes based on relative volatility. Table 3 classifies common manure odorants into top, middle, and base notes. Knowing that all notes do not have the same persistence can explain why the strength of farmstead odors changes over time. Consider the results shown in Table 4 from a study conducted in England. Different types of swine waste were applied 0.2 inches deep to soil inside a wind tunnel. Samples of air were collected and presented to a panel to determine odor offensiveness, concentration, and intensity immediately after spreading, and again four to six hours after application. Let us look at the results of this experiment as if the swine waste were perfume. The panel decided raw manure was definitely offensive. Odor intensity was extremely strong directly after applying raw manure, and intensity remained extremely strong six hours after application. The odors released by raw manure exposed at the soil contained persistent, strong-smelling odorants. Using perfume terminology, raw waste is heavy on the base notes.

Anaerobically digested manure paints a different picture. Anaerobically digested manure was described by the panel as faintly offensive. Initial intensity was extremely strong Ðas it was for the raw manure. Odors from anaerobically digested manure did not persist, however. Six hours after application, the panel smelled only faint odors in the samples. This means the anaerobically digested manure contained more top notes and less base notes. These results are consistent with the chemistry of anaerobic digestion. During digestion base notes (organic acids, skatole, and large organic sulfides) are converted to top notes (hydrogen sulfide, and ammonia) and odorless gases (carbon dioxide, methane).

Treating the raw manure by aeration reduced odors even further than anaerobic treatment. The panel described screen manure aerated at 1 to 2 mg/l dissolved oxygen as inoffensive. Why did land application odors increase with time? Why did they rise from no odor right after application to a faint odor four hours later? Aerobic bacteria are produced as raw manure is aerated, creating a large, living biomass. The aerobic biomass dies when exposed to a new environment by land application. The biomass decays anaerobically - releasing odorants similar to anaerobically digested manure.

Table 4. Odor Offensiveness, Concentration and Intensity of Land Applied Swine Wastes Based on Wind Tunnel Experiments in England.

Type of Waste	**Offensiveness**	**Highest Measured Odor Concentration (OU/m3)**		**Highest Measured Odor Intensity**	
		Initial	***After 4-6 hours***	***Initial***	***After 4-6 hours***
Raw Manure	Definitely Offensive	1740	320	Extremely Strong Odor	Extremely Strong Odor

Raw Manure Passed Through Screen	Definitely Offensive	250	190	Extremely Strong Odor	Extremely Strong Odor
Raw Manure Stored 14 days	Faintly Offensive	460	60	Very Strong Odor	Distinct Odor
Anaerobically Digested Manure	Faintly Offensive	350	45	Extremely Strong Odor	Faint Odor
Anaerobically Digested Manure Stored 14 days	Faintly Offensive	83	39	Strong Odor	Distinct Odor
Screened Manure Aerated at Low Dissolved Oxygen	Faintly Offensive	280	100	Distinct Odor	Faint Odor
Screened Manure Aerated at 1-2 mg/l Dissolved Oxygen	Inoffensive	60	61	No Odor	Faint Odor

Methods of Odor Measurement

Scentometer
A scentometer is a simple, hand-held odor dilution device used to measure odor concentration in the field. The person taking measurements holds the device up to his nose and breaths through the scentometer. Gases can either pass directly to the nose or pass through an activated carbon filter. The analyst chooses dilution factor by selecting the size of the hole passing unfiltered air. Advantages of the scentometer are its portabilty, its simplicity of use, and its ability to give immediate values for odor concentration and intensity. It is particularly useful for measuring intensity of odor sources. The main disadvantage is that it is difficult to overcome the analyst's personal bias in measurement. Also, the analyst's ability to distinguish odors diminishes the longer he is exposed to odors. Scentometer readings taken after an hour of sniffing may vary from readings taken when first arriving at the farm.

Olfactometer
An olfactometer is a laboratory device that distributes sample dilutions to odor panelists. A sample is collected at the farm and stored in a teflon or kevlar bag and brought into the laboratory. There are a number of variations on the olfactometer, but all devices do the same thing: the original sample is diluted with a stream of odorless gas and presented to a sniffer. Olfactometry is used to measure odor concentration, intensity, and offensiveness. Flexibility of use is the main advantage. Disadvantages are expense of operation and difficulty collecting representative samples of odorous gas.

Electronic Nose
Electronic noses mimic the human olfactory system using polymer sensors to simulate receptors in the nose and a computer to simulate the brain. Chemical composition of sensors is altered so each sensor responds differently to a given odorant. The main use of an electronic nose is to compare differences between mixtures of odors. The primary drawback is the electronic nose must "learn" a pattern of sensor responses before it can make future comparisons. Work is underway to devise electronics that will allow the nose to "guess" new odors. If properly trained, electronic noses may prove valuable in measuring odor character. A second drawback is, at the current level of technology; electronic noses are not sensitive at low odor concentrations.

Chemical Methods
Chemical methods are used to determine the actual concentration of individual odorants in a sample taken from the field. The most common instrument used in odorant analysis

is a gas chromatograph with a mass spectrometer detector. Like the electronic nose, a gas chromatograph distinguishes compounds by comparing to a reference standard. The main drawback to chemical methods is the shear number of potential odorants needed to analyze in a single sample of farmstead odors.

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